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Compressed Video Applications Through Mobile Satellite Communications

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ABSTRACT

The National Aeronautics and Space Administration (NASA) has been involved in the development of an experimental K- (20 GHz) and Ka-band (30 GHz) satellite known as the Advanced Communications Technology Satellite (ACTS). The Jet Propulsion Laboratory (JPL) has been commissioned to develop two different mobile satellite communication (satcom) terminals to operate with ACTS. The first terminal, which has been completed and tested, the ACTS Mobile Terminal (AMT), has been designed to operate at low data rates (2.4/4 .8/9.6 kbps) and medium data rates (64/128 kbps), and potentially higher. The second terminal, still under development, the Broadband Aeronautical Terminal, will operate at a minimum of 384 kbps, and potentially up to a full T1 data rate (1 .544 Mbps).

Working with interested groups within U.S. industry, a series of applications-oriented experiments have been developed which will demonstrate compressed video (using commercially available video compression products) via mobile satcom. Such diverse applications as advanced scouting and video teleconferencing (U.S. Army Satcom-on-the-Move), Satellite News Gathering (SNG) (NBC), telemedicine (University of Washington Medical Center), telescience/tele-education (NASA Ames Kuiper Airborne Observatory), remote infrared imaging (NASA Ames), and commercial/government aeronautical video services (Rockwell International/Collins Corporation) have been/will be demonstrated and evaluated through this program. This paper will describe the setup and objectives for each of these experiments, specifically how they relate to video compression techniques, and provide experimental results were where. available.

INTRODUCTION

Throughout the eighties NASA, through JPL, has been involved in the development and demonstration of system concepts and high risk technologies to enable the introduction of commercial mobile satellite services (MSS). This initial effort occurred at L-band (1.5 GHz), and currently commercial L.-band MSS are available through a host of U.S. and international companies. It is expected that the present allocation for L-band MSS will become saturated by the turn of the century. In view of this, and the already existing non-MSS frequency allocations at other bands (C-, X-, and Ku-bands for example), NASA and JPL have focused on K- and Ka-bands for further expansion of MSS.

K- and Ka-bands have outstanding potential for higher data rate communications and more highly diversified MSS for a number of reasons. Unlike L-band, K- and Ka-bands have a significant amount of bandwidth (500 MHz at each K- and Ka-bands) already allocated for MSS services, Moreover, these higher frequencies can support antenna designs that while physically smaller than their L-band counterparts, typically can provide higher gain, typically 10 dB or more, K- and Ka-bands, therefore, are an excellent candidate for the pursuit of larger capacity services for commercial users (i.e., compressed video). Satellite communication system design at these higher frequencies, of course, do pose significant technical challenges. They include: a young technology with lossy RF components; significant rain attenuation; potentially large frequency uncertainties; and large Doppler shifts due to vehicular motion.

NASA has provided the platform for the initial evaluation and exploitation of K- and Ka-bands through their development of the ACTS. JPL's goal, through the use of ACTS and the development of the AMT and the Broadband Aeronautical Terminal, is to overcome these technical challenges with a system architecture and components that will exploit the potential benefits of such a migration from L-band. The final phase of this effort has been and continues to be the transfer of such technologies to interested groups within U.S. industry. The expedition of this process is occurring through the involvement of these same industrial organizations in the planning and participation of various applications-oriented experiments with this equipment.

The remainder of this paper will present a general description of the system design utilized through this experimental program including the satellite itself, as well as both mobile ground terminal developments. Furthermore, a detailed explanation of the various experiments that have been conducted or are in the process of being planned will be presented. Finally, the experiment results to date will be provided.

SATELLITE CHARACTERISTICS

ACTS is a geosynchronous satellite that is located at 100° west longitude and was launched by NASA from the space shuttle in September 1993. It contains on-board fuel for approximately 4.8 years of operations. This satellite possesses many advanced, high risk technologies not found in any other satellite. Amongst its more salient features include a dual operational mode. In addition to the more traditional FDMA, "bent-pipe" mode known as the Microwave Switch Matrix (MSM)[1], this satellite can also operate in a Baseband Processor (BBP) mode. For this TDMA scheme of operation, the received signal on-board the satellite is actually demodulated and demodulated before being downlinked. Both of these modes of operation allow for the flexible connectivity of any number of input and output ports associated with the multi-beam antenna (MBA) subsystem.

Unlike most traditional satellites that provide full hemispherical coverage typically with a single antenna pattern, ACTS has a multitude of highly concentrated spotbeams located on key areas around the country. These high gain spotbeam antennas allow for higher throughput capacity (than typical hemispherical satellite coverage), but in a

[1] This is the mode of operation of the satellite that both mobile terminals utilize.

smaller area (typically over an area approximately 120 miles in diameter). Specifically, fixed spotbeams are located on Cleveland, Ohio, Atlanta, Georgia, and Tampa, Florida. In addition, isolated hopping spotbeams are located over such metropolitan areas as Los Angeles/San Diego, San Francisco, Seattle, Denver, Dallas, etc. Furthermore, two clusters of hopping spotbeams provide continuous coverage over the northeastern United States between Chicago, Illinois and Washington, D.C. and southern Virginia to Boston, Massachusetts. To cover the less populated areas of the country, a mechanically steerable spotbeam has also been designed into this satellite which can be programmed to cover any area in the western hemisphere from west of Hawaii to the western shore of England, A complete picture of ACTS' spotbeam coverage is provided in Figure 1. A further detailed technical description of the characteristics of this satellite can be found in [1].

MOBILE TERMINALS DESCRIPTION

AMT

The complete technical details on this terminal can be found in [2]. The AMT can be broken down into two broad divisions, namely, the baseband and microwave processors. The baseband processor typically consists of a video codec, a modem, and a terminal controller (TC). Also included as part of this setup, strictly for experimental purposes, is a Data Acquisition System (DAS). The elements of the microwave processor are: the IF Converter (IFC), the RF Converter (RFC), the antenna controller, and the antenna.

The TC is the "brain" of the terminal. It contains the algorithms that translate the satcom protocol into operational procedures and interfaces to all of the other terminal subsystems. The TC also is responsible for providing the user with a system monitoring capability, and a variety of test functions during experimentation, such as bit stream generation and bit error rate (BER) calculations.

Two different modems have been used as part of the AMT. The baseline AMT modem, that was designed in-house, implements a simple yet robust DPSK scheme with rate 1/2 convolutional coding and interleaving. The performance specification for this modem is for a BER of 10^{-3} at an E_b/N_o of 7 dB in AWGN. Further capabilities have been built into this modem to compensate for frequency offsets of up to 10 kHz with an additional performance degradation of only 0.5 dB. This modem is operational at 2.4, 4.8, and 9.6 kbps. The second modem that has been utilized as part of this setup is a commercially bought satcom modem that includes such features as coherent BPSK with convolutional coding, concatenated coding (Reed-Solomon), and interleaving. The performance specification for this modem is for a BER of 10^{-6} at an E_b/N_o of 5 dB in AWGN. This modem is operational at data rates from 9.6 kbps to 2.048 Mbps.

The vehicle antenna is the critical K-/Ka-band technology item in the microwave processor, The design of this antenna called for a "passive" elliptical reflector-type antenna to be used in conjunction with a separate high powered amplifier. Complete with a spherical radome, it stands approximately 5 inches in height, and is approximately 8 inches in diameter at its base. This antenna is fully tracking in azimuth, while manually positioned in elevation to one of five distinct settings.[2] Combined with a 10 W TWTA, this antenna system provides at least 32 dBW transmit EIRP on boresight. The 3 dB beam width is 12') and 18° in azimuth and elevation, respectively. Receive specifications for this antenna have been set at -5 dB/°K, once again on boresight.

The antenna pointing system enables the antenna to track the satellite for all practical land-mobile vehicle maneuvers. The antenna is mated to a simple, yet robust, mechanical steering system. A scheme wherein the antenna is smoothly dithered about its boresight by about a degree at a rate of 2 Hz is used, The pilot signal strength is measured through this dithering process, and is used to compliment the inertial rate sensor's information. The combination of both pieces of this information allows this particular antenna scheme to track the satellite even when experiencing a shadowing event of up to 10 seconds in duration.

Preceding (or following) the antenna, the RFC converts an IF signal around 3.373 GHz to (from) 30 (20) GHz for transmit (receive) purposes. The IFC translates signals between 3.373 GHz and a lower 70 MHz IF at the output/input of/to the modem. A key function of the IFC is pilot tracking and Doppler compensation (for the return communications link).

Broadband Aeronautical Terminal

As part of the ongoing effort to investigate commercial applications of ACTS technologies, NASA's Jet Propulsion Laboratory and various industry/government partners are developing a broadband mobile terminal for aeronautical applications. The ACTS Broadband Aeronautical Terminal is being designed and developed to explore the use of K- and Ka-band for high data rate aeronautical satellite communications. Currently available commercial aeronautical satellite communications systems are only capable of achieving data rates on the order of tens of kilobits per second. The broadband terminal, used in conjunction with the ACTS mechanically steerable antenna, can achieve data rates of 384 kbps, while use of an ACTS spot beam antenna with this terminal will allow up to T1 data rates (1 .544 Mbps). The aeronautical terminal will be utilized to test a variety of applications that require a high data rate communications link. Beyond these applications, it is thought that if a wideband communications pipe is made available, unforeseen applications will develop. The use of the K/Ka-band for wideband aeronautical communications has the advantages of spectrum availability and smaller antennas, while eliminating the one major drawback of this frequency band, rain attenuation, by flying above the clouds the majority of the time.

The specific objectives of the experiments to be performed are: (1) demonstrate and characterize the performance of high data rate aeronautical Ka-band communication (2) characterize the propagation effects of the communications channel during take-off, cruise, and landing phases of flight, (3) provide the systems/technology groundwork for an eventual commercial Ka-band aeronautical satellite communication system. The experiments will demonstrate real-time digital compressed video/data transmissions

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[2] These five settings allow for complete elevation coverage for the continental United States.

both to and from a variety of platforms, including a business jet, commercial airline, military aircraft, and unmanned remotely piloted helicopter. The aeronautical terminal is currently undergoing development in preparation for experiments that will commence in July 1995.

A block diagram of the terminal is depicted in Figure 2. The terminal development will leverage off the technologies developed under the ACTS Mobile Terminal (AMT) project at JPL. The high gain aeronautical antenna will employ an azimuth and elevation pointing system to allow it to track the satellite while the aircraft is maneuvering. The commercial video codec will compress/decompress full motion video in real time as well as insect the aircraft position information into the data stream which is then passed to the modem. The data acquisition system will record all relevant terminal parameters to aid in the characterization of both the aeronautical terminal equipment and the communication channel. The aeronautical antenna and radome are being developed by EMS Technologies, Inc. The antenna design utilizes a slotted waveguide array, is mechanically steered in both azimuth and elevation, and is designed to enable mounting on a variety of aircraft. The radome is hat shaped with a height of 6,7" and a 27.6" diameter; roughly the size of the Sky Radio radome currently flying on United Airlines and Delta Airlines. A detailed technical description of this terminal can be found in [3].

Video Codecs

The video codecs utilized by the AMT and the BAT are existing (off-the-shelf) codecs. In an effort to select an appropriate video codec for the land mobile and aeronautical mobile satellite communications environment, codec requirements were specified, an exhaustive survey of video codec manufacturers was performed, and codec trials of three codecs were conducted at JPL. A summary of the codec requirements is given in Table 1. The surveyed video codec manufactures included: Compression Labs, VTEL, NEC, British Telecom, Panasonic, ABL, Hitachi, PictureTel, Mitsubishi, Horizons, UVC, and a variety of compression board manufacturers. A crucial part of this survey was attending the annual Video Telecommunications Conference (VTC) to make qualitative evaluations of the video quality at the data rates of primary interest. Circumstances were such that after the list of candidates was narrowed, actual laboratory tests and satellite experiments were performed with the ABL, CLI, and NEC video codecs.

The ideal video codec for land and aeronautical mobile applications has characteristics that are not necessarily important when the codecs are utilized in their traditional role of fixed site video teleconferencing. The land mobile satellite communications channel is prone to periods of signal outage due to obstacle shadowing. Signal outages necessarily require the video codec to regain synchronization rapidly when the signal returns. The best outage recovery performance that could be had with existing video codecs was on the order of three seconds after the codec started receiving valid data. The mobile satcom channel typically has a higher bit error rate than do the communication channels which the video codecs typically encounters. As a result it is critical that the codec degrade gracefully in the presence of high bit error rates and and ~~again~~ recover rapidly from these errors. Some video codecs were found to have a tendency to “hang” or freeze in the presence of high bit error rates, requiring the power to be cycled.

Other required codec features that are not as important in fixed site applications are that the codec be small in size, light in weight, somewhat rugged in construction, and capable of multiplexing multiple external data sources with the compressed video data stream,

In evaluating the codec video quality the performance at data rates from 128 kbps to 384 kbps was deemed to be most important for the planned mobile SATCOM experimental applications. Most video codecs were found to provide very good quality video at data rates approaching TI (1 .544 Mbps), but there were significant differences in quality at the data rates of interest, Quality varied significantly primarily in image resolution, but also in motion handling capability. All the video codecs had their own advantages and disadvantages, but on the whole the NEC video codec was determined to be the currently available codec most appropriate for future SATCOM experiments.

EXPERIMENTS

While the specific description of a number of different compressed video related experiments is provided in the following subsections, a general description for all of these experiments is provided in this section. Full-duplex communication between a fixed station and a mobile terminal (via ACTS) occurred as follows. For the forward link (fixed station-to-ACTS-to-mobile terminal), two signals were provided: a pilot tone and a data/voice/video signal. The uplink center frequency was 29.634 GHz (the pilot tone is transmitted at an uplink frequency of 29.631 GHz). The translated downlink frequency was 19.914 GHz (the pilot tone’s downlink frequency is at 19.911 GHz). The chosen transmit and receive frequencies are tunable over a 300 MHz bandwidth. The pilot signal is used by the mobile terminal for many functions. The most prominent use of this signal is to aid in tracking by the vehicular antenna. Furthermore, this reference pilot signal is a useful tool for the mobile terminal to estimate any Doppler and other frequency uncertainties within this system setup. This general experiment configuration is provided in Figure 3.

The initial two experiments to be conducted with the aeronautical terminal are shown in the Figures 4 and 5, respectively. Rockwell/Collins is working with NASA/JPL to develop the terminal and integrate it into a Rockwell Saberliner aircraft to demonstrate the transmission of compressed video both to and from the aircraft. NASA Ames Research Center will be flying the terminal in the Kuiper Airborne Observatory to transmit imagery from the aircraft for an educational broadcast and to conduct remote tele-science. Beyond these two experiments, several additional experiments with industry and government partners are in various stages of planning.

U.S. Army CECOM Satcom-on-the-Move Experiment

This past summer JPL, in conjunction with the U.S. Army CECOM, conducted a series of experiments and demonstrations utilizing ACTS for military applications. Specifically, 64 and 128 kbps full-duplex compressed video transmissions were used for mobile video teleconferencing and advanced scout imaging, The mobile vehicle used during these tests was a U.S. Army-supplied Highly Mobile Multi-purpose Wheeled Vehicle (HMMWV) with an S-250 shelter for housing the satcom equipment, CLI, Inc. Rembrandt II video codecs were used in these tests.

This state-of-the-art technology was demonstrated throughout the United States at seven different sites. The military reaction to these tests were highly favorable. Typical military communication capabilities is limited to SINCGARS radio which not only limited in throughput capacity (16 kbps maximum data rate), but also in range (terrestrial communications). Even the various mobile satcom capabilities that exist through the MILSTAR Program are limited in data rate (on the order of a few kbps). This demonstration with ACTS and the AMT proved to be a more advanced system capable of allowing the U.S. Army to achieve many new and exciting uses of mobile satcom. Further tests within the U.S. Army are proceeding this year through the communications command and control of an robotic Unmanned Ground Vehicle (UGV).

NBC SNG Experiment

Current communication capabilities for an SNG setup is currently limited to cellular telephone (where available) while mobile. Furthermore, while communications can typically be expanded to include video capabilities once the SNG van is stationary, the whole setup is rather large and unwieldy. Utilizing ACTS and the AMT, a series of experiments and demonstrations were accomplished which overcame both of these deficiencies. A picture of the experimental van parked side by side with a typical operational SNG van is provided in Figure 6 (the experimental van is the one on the left). Note the tremendous size difference between the two vehicles' antennas.

Full-duplex compressed video communications at data rates up to 768 kbps, both while fixed and mobile, was established between an experimental van located in the greater Los Angeles area and a fixed station that was located at NASA LeRC in Cleveland, Ohio. The communications link was further enhanced by terrestrially connecting (via a fractional T1 data line) the fixed station with NBC New Headquarters located in New York, New York. Two different types of video codecs were used in this experiment: ABL's VT2C and NEC's VisuaLinks 5000EX. Both of these video codecs worked quite well under the conditions that were experienced over the mobile satcom link.

University of Washington Medical Center Telemedicine Experiment

Vast regions of the United States does not have access to the advances in medical technology over the past decade. This particular experiment will link rural America to these technologies in the metropolitan areas, and research hospitals associated with many universities. Specifically, the University of Washington Medical Center, known for their capabilities and advances in radiology, will be linked to many different locations throughout the northwestern United States via ACTS and the AMT. This experiment is scheduled to take place during the summer of 1995. The data rates that are targeted for this experiment are 64 kbps and 128 kbps. Once again, the NEC VisuaLinks 5000EX will be utilized. One particular objective that these tests will try to evaluate is the quality of a transmitted 64 kbps or 128 kbps still image for reliable medical diagnosis. Such types of medical applications as X-Hays, Magnetic Resonance Images (MRI's), and Computed Topographies (CT's) will be evaluated.

KAO/ACTS Experiment

JPL, working cooperatively with NASA Ames, will be conducting a series of experiments on the Kuiper Airborne Observatory (KAO) that will utilize the ACTS. These experiments will take place September 1995. The JPL developed ACTS Broadband Aeronautical Terminal will be installed in the KAO (a C-141) to allow the establishment of a full-duplex 384 kbps satellite communications link between the aircraft and the ground. There are currently four planned components of this experiment. These are:

1) Television broadcast/interactive classroom - a F'BS produced live television broadcast entitled “Live from the Stratosphere”. As part of the broadcast students watching the live video from the aircraft will be able to ask questions via voice link to the aircraft.

2) Downlink to the San Francisco Exploratorium (and possibly Adler Planitarium in Chicago).

3) Telescience demonstration - demonstrate remote control of scientific instruments onboard the KAO.

4) System Health Monitoring - demonstration/test of a system that remotely monitors scientific instruments onboard the KAO.

Rockwell International/Collins Corporation Commercial/Government Aeronautical Services Experiment

Rockwell and JPL are currently working together on an experiment design that will investigate the feasibility and limitations of airborne Ka-band satellite communications. This experiment involves the installation of the Broadband Aeronautical Terminal into Rockwell's Saberliner 50 aircraft for a series of demonstration flights. The specific objectives of this experiment are:

1) Determine the feasibility of high data rate communications, in particular compressed full motion video, to and from an airborne platform under varying weather conditions.

2) Determine the feasibility of slaving the steerable satellite antenna to an onboard aircraft Global Positioning System (GPS) receiver in order to automatically follow the flight path of the aircraft, allowing the highest possible data rate channel for critical applications.

This experiment has applications to both commercial aviation and government airborne services. Airlines wish to offer live video and high bandwidth multimedia services to passengers, but currently do not have the necessary bandwidth capacity to the aircraft, Various government entities have mission requirements to transmit and receive real-time video between mobile terminals and earth terminals. This particular experiment is slated to take place during the latter part of 1995.

The aeronautical terminal will utilize the ACTS mechanically steerable antenna and the MSM to communicate with the ground station. The aeronautical terminal will relay position information (GPS) to the ground station which will be used to command the ACTS antenna to point precisely to where the aircraft is located. This will allow the aircraft to fly and communicate anywhere on earth that is visible to ACTS.

SUMMARY

Many new and exciting mobile satcom applications exist for commercially available video compression products and techniques. State-of-the art mobile satcom capabilities available through the ACTS Program and JPL can currently support upwards of several hundreds of kilobits per second of throughput capacity, and in some circumstances as much as a megabit per second. Through such successful demonstration and experimental programs as ACTS, it is believed that the mobile satellite systems of the future will be able to support several orders of magnitude higher throughput, thus still increasing the possibilities and applications of compressed video. Through the ACTS Program, a quantum leap in mobile satcom system capacity has been achieved, thus making medium data rate video compression techniques for such an application a reality. These initial tests have been looked upon quite favorably by interested users in the satcom community. Continued technological advances should push the mobile satcom system designs of the future to even higher throughput capacity.

REFERENCES

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[2] Dessouky, K. and Jedrey, T., "The ACTS Mobile Terminal (AMT)," AIAA, November 1992.

[3] Agan, M. and Densmore, A., "NASA's K/Ka-Band Broadband Aeronautical Terminal For Duplex Satellite Video Communications," NTC, May 27, 1994, San Diego, California.

Table 1 Video Codec Requirements

weight	< 4 0 lbs.
height	<7"
compressed video rates	56 kbps to 2.048 Mbps
compressed audio rates	16 kbps to 64 kbps
image quality	high compressed image quality at all data rates
voice quality	high compressed voice quality at all data rates
power consumption	<300 Watts
ber performance	operate without degradation at 10^{-6}
operating temperature	typical of aircraft environment
operating humidity	typical of aircraft environment
clocking	independent transmit and receive data rates
broadcast capability	must be capable of transmitting while the receive is disabled, must be capable of receiving while the transmit is disabled
RS232 data ports	minimum of two ports
video format	NTSC
line interface	RS449 line interface
mounting scheme	rack mount hardware required

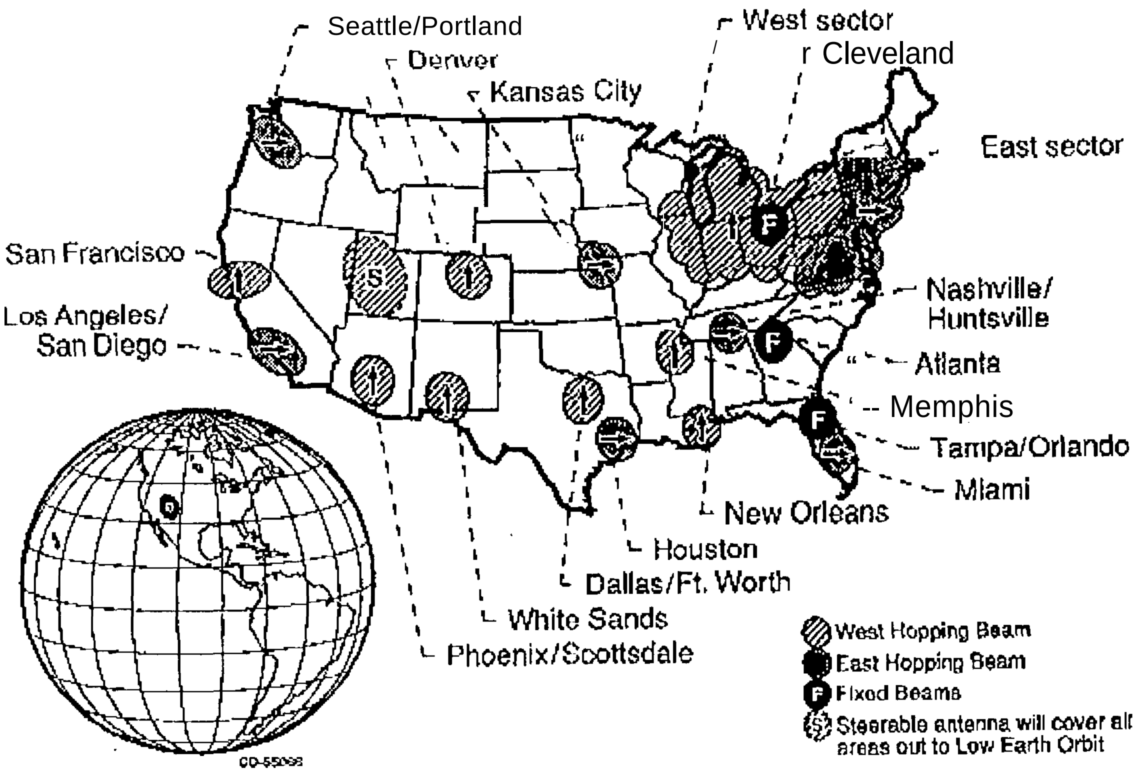
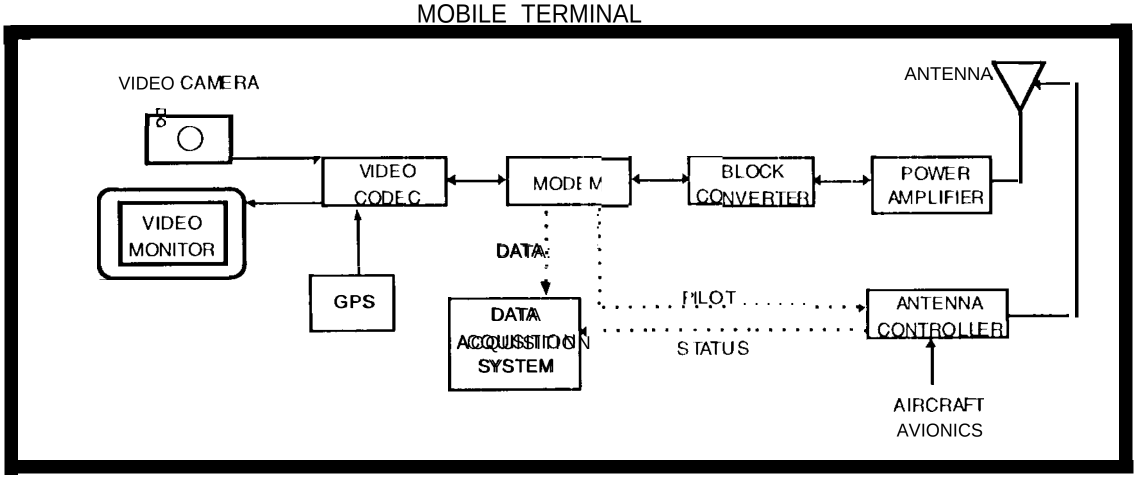


Figure 1 ACTS Spotbeam Coverage

MOBILE TERMINAL



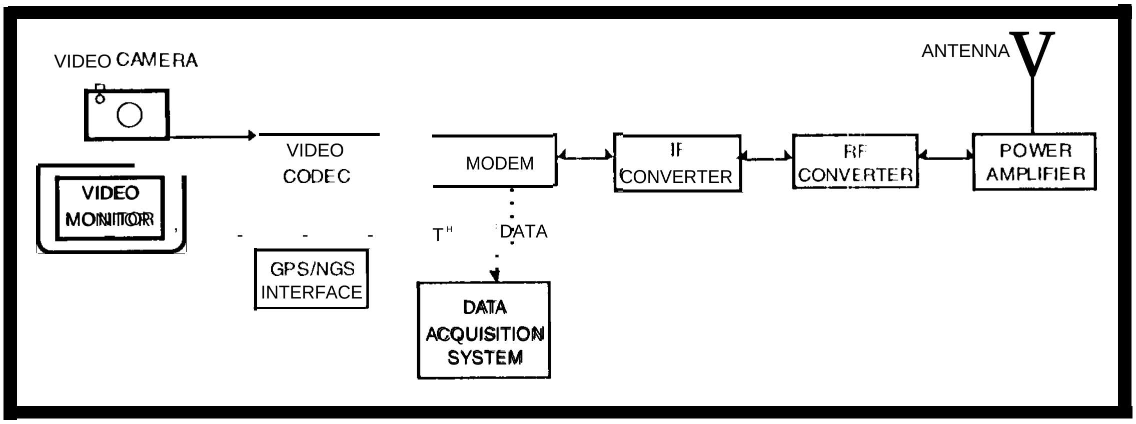


Figure 2 Broadband Aeronautical Terminal Block Diagram

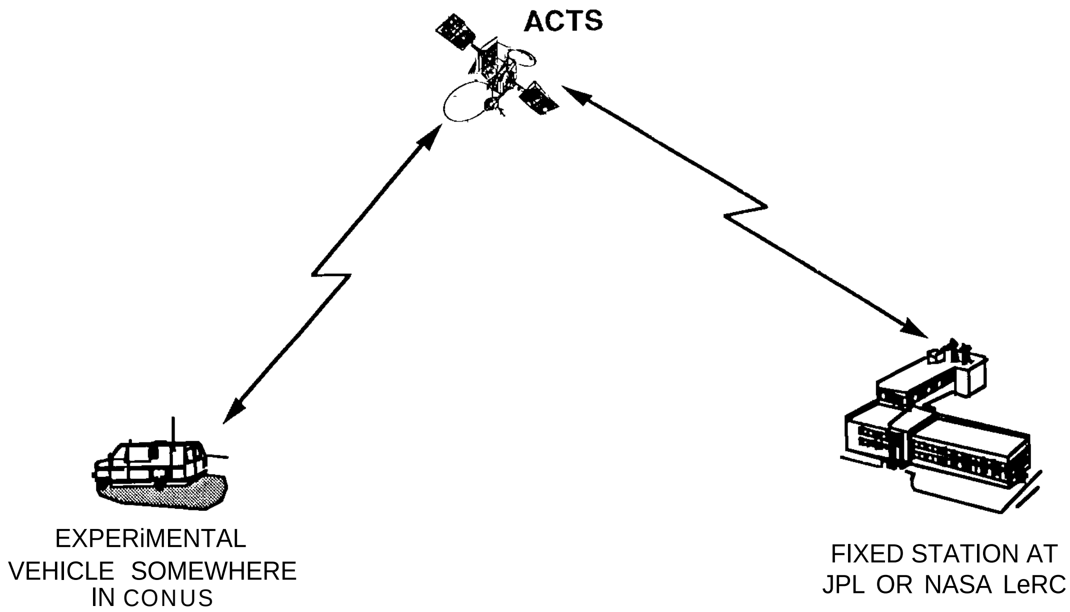


Figure 3 General Experiment Configuration

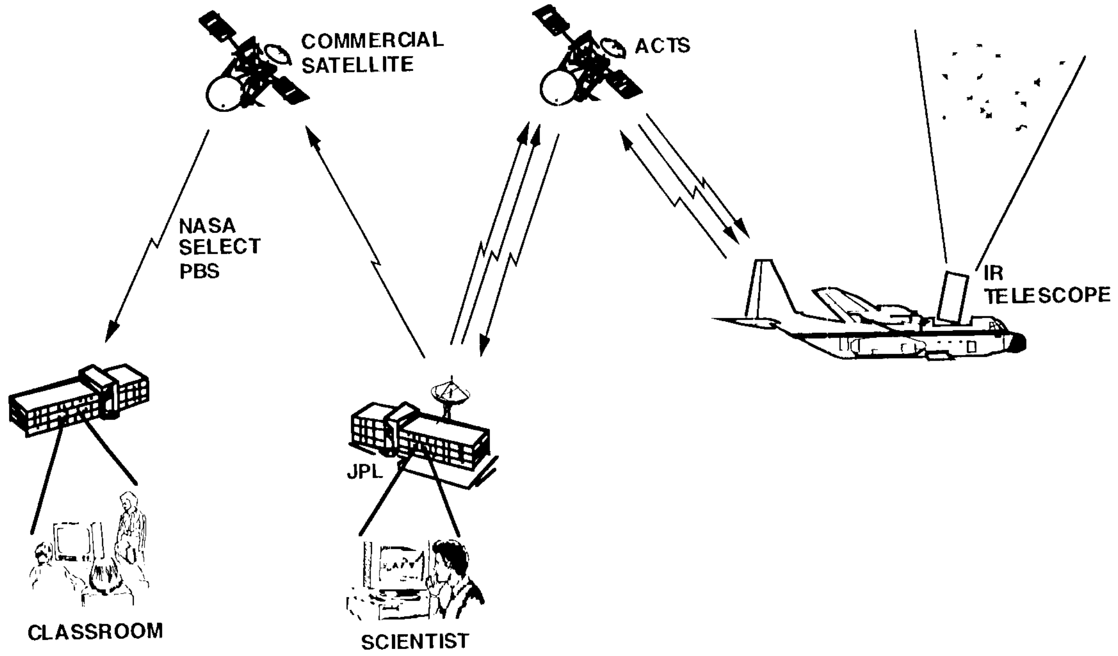


Figure 4 KAO/ACTS Experiment Configuration

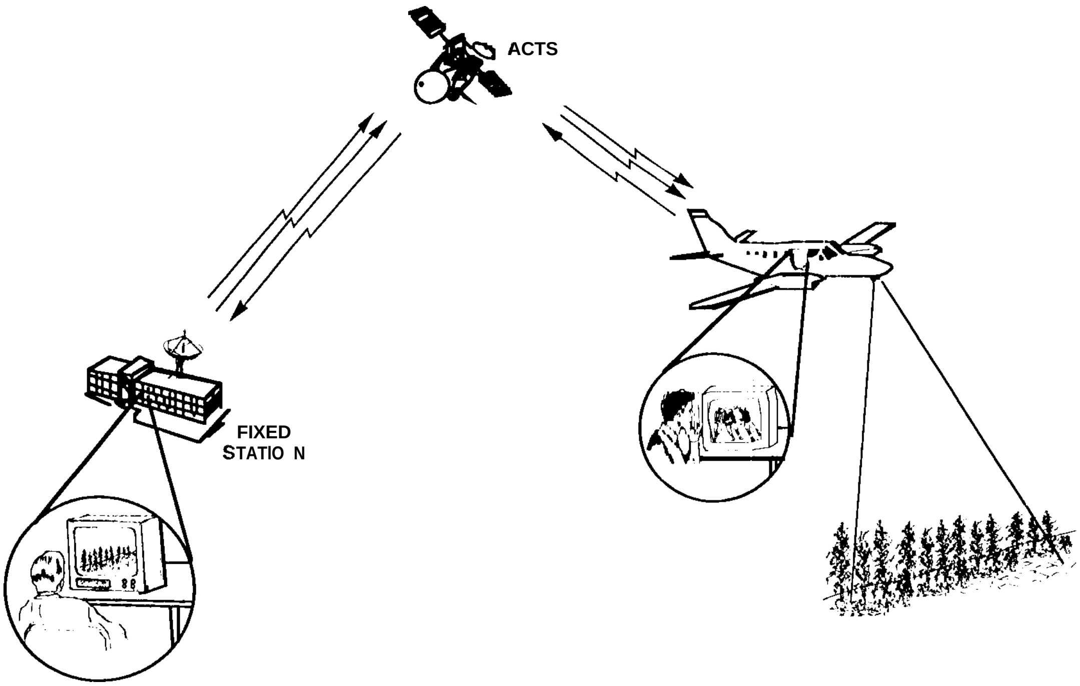


Figure 5 Commercial/Government Aeronautical Services Configuration

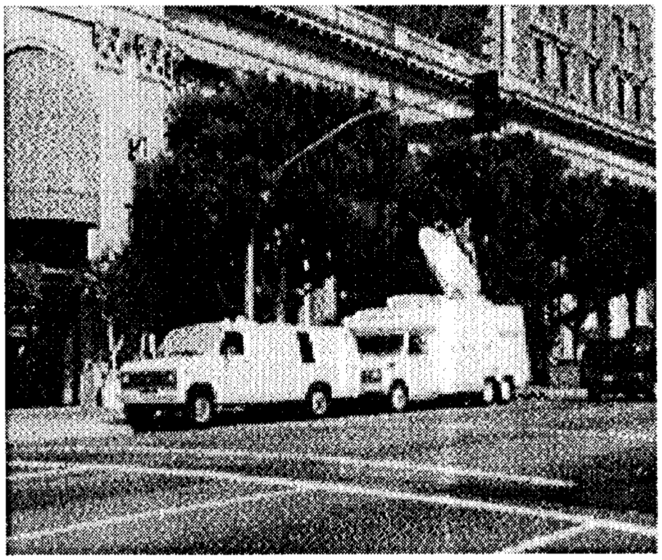


Figure 6 Size Comparison Between SNG Van of Today and Tomorrow